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ELECTROMAGNETIC RADIATION SYSTEM (EMRS) FOR SUSCEPTIBILITY TEST--ETC(U)

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Research and Development Technical Report

ECOM-76-0332-4

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ELECTROMAGNETIC RADIATION SYSTEM (EMRS) FOR SUSCEPTIBILITY TESTING.

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FOR SUSCEPTIBILITY TESTING

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The function of the Electromagnetic Radiation System (EMRS) is to generate electromagnetic energy so as to produce a constant field strength that can be automatically scanned as a function of frequency. The design objective is to cover the frequency range of 30 hertz to 40 gigahertz with field strength intensities up to 200 volts per meter. A stripline approach is described and proposed for use as the field generating device for the

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lower frequencies. The use of defocused parabolas are proposed for use at the higher frequencies. Also described are system components including; sweep oscillator, power amplifiers, tunable filters and associated control circuitry.

TABLE OF CONTENTS

I. INTRODUCTION

As outlined in the EMRS Design Plan, the goal of the demonstration EMRS is to generate a field intensity of 200 volts per meter. In addition, the system should provide this field strength over four frequency bands ranging from 30 MHz up to 18 GHz. The bands within this broad range are to be selected in order to demonstrate EMRS operation using the stripline and refocused parabola antenna. Switching between each band can be done either manually or under computer control.

Within each band, the frequency should be variable using a sweep mode or with manual tuning. Capability for manual and computer control of frequency and field intensity is required. Such a system would be able to tailor frequency and field strength to fit special test requirements. A pure signal is also required. To achieve this, filtering of the output signal would reduce harmonic distortion, spurious signals and broadband noise. Automatic leveling should be provided to maintain a constant preset field strength over the frequency band being swept. During the period of this report, progress has been made toward the implementation of the EMRS design plan. Work has proceeded in the following areas.

1. Detailed specification of EMRS requirements.
2. Specification and selection of EMRS subsystems including
   a. Sweep oscillator
   b. Power amplifiers
   c. Interconnection cabling
3. Study of Tracking filter requirements.
4. Fabrication and testing of antenna systems.

A preliminary block diagram of the proposed demonstration EMRS is shown in figure 1.

II. SUBSYSTEM CONSIDERATIONS

1. The EMRS Design Plan dated May 1977 provided general guide lines for EMRS performance. The following general specifications were defined.

   a. Frequency bands to be covered:

      Octave range between 10 MHz and 1 GHz

      1 - 2 GHz

      2 - 4 GHz

      12.4 - 18 GHz

   b. Antenna

      Strip Transmission Line for 10 MHz to 1 GHz

      Strip Transmission Line for 1 - 2 GHz

      Refocused Parabola for 2 - 4 GHz

      Refocused Parabola for 12.4 - 18 GHz

   c. Signal Source

      Manual or Automatic sweep

      Variable output with linear dynamic range of 53 db.

      Automatic leveling to maintain constant field intensities between 0.001 to 200 volts/meter at test sample

   d. Filters

      To achieve the signal purity goals of 100 dbc for harmonic and non harmonic components of the system output, a filter for each of the frequency band defined in 1.a. is required. The filters are tunable with sharp roll-off.

2. In addition to the general specification for EMRS defined above, the following detailed specification were developed during the period of this report.

a. Frequency bands.

1) For the frequency range 10 MHz to 1 GHz, an octave band 30 to 60 MHz was chosen. The rationale for choosing this octave band is that 30 to 60 MHz is in the frequency range of operation of many military F.M. receiver-transmitters.

2) The remaining frequency bands in 1.a. will be used.

b. Filter considerations.

1) Signal purity requirements for EMRS are that the harmonic and non-harmonic power output of the system should be 100 db below the level of the fundamental frequency.

2) To achieve these attenuation levels, two possibilities were considered: Switchable half octave low pass filters could be included as part of the power amplifiers or; a narrowband tunable filter designed to track the center frequency of the sweep oscillator would follow the power amplifier.

In considering the use of two half octave switchable filters to cover an octave band, it was found that inadequate attenuation of non harmonics was obtained. Hence a narrow band tracking filter would be required in conjunction with the low pass filters to eliminate nonharmonic components and to reduce broadband noise.

It was decided that since a tunable filter was required even with the half octave filters, the tunable filter would be designed to provide for the rejection of the harmonics also. This would eliminate the need for and the expense of the half octave filters.

The Preliminary specification of the tracking filters are described in Appendix A. A more detailed specification of the tracking filter requirements will be determined during the next report period.

c. Signal sources.

Sweep oscillator systems from three different manufacturers were considered: Hewlett-Packard, Systron-Donner and Microtel. In comparing the systems of each, consideration was given to the following areas:

1) Frequency bands covered
2) Power output
3) Frequency accuracy
4) Sweep linearity and accuracy
5) Flexibility for future expansion
6) AM, FM, and pulse modulation capabilities
7) Remote digital control capability using standard IEEE-488/75 Bus
8) Overall impact on EMRS cost

The sweep oscillator system compared were the following:

1) Hewlett-Packard model 8620C with plug in's - 86320B (10 to 2000 MHz), 86331C (1.7 to 4.3 GHz) and 86260A (12.4 to 18 GHz).
2) Systron-Donner model 50525-1
3) Micro-Tel Model SG-811A

Of these three systems, the HP model 8620C best fits the overall requirement of EMRS except for one serious drawback. In the frequency band 30 to 60 MHz, using the 86320B RF module, the frequency accuracy at 30 MHz is $\pm$ 20 MHz. This degree of frequency inaccuracy precludes the use of a narrow band tracking filter to meet signal purity requirements.

The Microtel model SG-811A has similar inaccuracy at 30 MHz and in addition is approximately 25% higher in price. The Systron-Donner system frequency accuracy is $\pm$ 1 MHz at 30 MHz. Because of the above consideration, the Systron-Donner is a tentative choice. The main limitations of the Systron-Donner system are low power output (10 mw), which requires a preamplifier in the system; lack of flexibility because the RF sections do not plug into the front panel; and low resolution of frequency (1000 points/band) under IEEE-488 Bus Control.

Further research of other manufacturers will be accomplished during the next report period.

A comparison matrix for the Hewlett-Packard and the Systron-Donner equipment is shown in figure 2. The Microtel model SG-811A was dropped from further consideration for cost reasons.

d. Power amplifiers.

The basic criteria for the power amplifier selection were:

1) Minimum Power output
2) Power gain
3) Harmonic distortion
4) Noise Figure
5) Output protection against reflected power assuming a Sweep Oscillator output of 10 dbm.

The EMRS requirements in each band are

	30 - 60 MHz	1 - 2 GHz	2 - 4 GHz	12.4 - 18 GHz
Min Power	100 watts	100 watts	200 watts	10 watts
Power Gain	40 db	40 db	43 db	30 db

The harmonic and nonharmonic output of the power amplifiers will be attenuated by filtering. Therefore, we were looking for the lowest harmonic distortion and noise figure consistent with the power output and gain requirements.

Frequencies from 1 to 18 GHz require traveling wave tube amplifiers to obtain the required power levels. The power amplifiers manufacturers considered for frequencies above 1 GHz included Logimetrics Inc., Kell Tech Inc., Varian, and Teledyne.

Of these manufacturers, only Logimetrics is able to supply units with sufficient power output and gain, and output protection against reflected power.

For the 30 to 60 MHz frequency range, solid state power amplifiers are available. Of those considered, the Electronic Navigation Industries, Inc., model 3100L, best meets EMRS requirements in that noise figure and harmonic distortion are superior to the others considered. It is anticipated that the power amplifier will be ordered during the next report period.

e. Antenna.

Work on the radiating subsystems has proceeded in two areas.

1. Stripline

The test box to be used to simulate a piece of test equipment has been completed and some initial testing begun. The purpose of this box is two-fold:

a. demonstrate the equivalency between the proposed stripline technique and the traditional antenna radiation technique for measuring RF susceptibility, and

b. determine the effects of apertures and protrusion in the stripline on the electrical characteristics of the stripline.

2. Refocused Parabolas

The parabolas and the field measuring probes are still in fabrication and are due early in the next reporting period. Initial measurements on the dishes will be antenna radiation patterns and gain measured at a distance of three (3) meters.

Phase center measurements were made on the AEL, Inc., model H-1498 horn to be used as the feed for the 2-4 GHz band. The purpose of this measurement was to determine the optimum feed location of the horn such that the phase variation on the reflector is minimized. A uniform phase front will produce the best patterns but this is not realizable over an octave band with a horn antenna. Phase variations in the aperture will result in increased sidelobes in the antenna radiation patterns.

3. Testing and Validation.

During the next report period, measurements will be made to demonstrate the equivalency between RF susceptibility measurements using the Stripline Technique versus the standard Antenna Radiation Technique. In addition, radiation patterns and gain of the refocused parabola will be measured at a distance of three (3) meters to determine coverage area, that area whose field strength is within 6 dB of the maximum field strength produced by the antenna, and to determine the power required to produce a 200 V/m field. These measurements will be made across the frequency band.

f. Modulation.

The EMRS Design Plan outlines the modulation requirements for the demonstration EMRS as follows:

FM: 0 to 10 MHz deviation with modulating frequencies of 100 Hz to 10 MHz.

AM: 0 to 50% modulation depth with modulating frequencies of 100 Hz to 10 MHz.

Pulse: Pulse width of 0.05 μsec to 5 millisec. at pulse rates of 100 Hz to 10 MHz.

The modulation capabilities of the sweep oscillators generally include AM and FM. For example, the HP-8620C sweep oscillator system has typically:

External FM:	Deviation	Modulating Freq.
	$\pm$ 75 MHz	DC to 100 Hz
	$\pm$ 5 MHz	100 Hz to 1 MHz
	$\pm$ 2 MHz	1 MHz to 2 MHz

External AM:

0 to 100% depth for DC to 150 KHz

Pulse:

Not included

As can be seen from the above, the modulation characteristics for a typical sweep oscillator fall short of the suggested EMRS system requirements especially for the AM bandwidth and pulse modulation. The FM capabilities, except for the somewhat narrower bandwith, are adequate.

To overcome the limitation on the AM and pulse modulation, an external modulator will be used. It will consist of a reflective PIN diode switch in series with the sweep oscillator output. Typical modulation depth is 40 db for a modulation current of 100 ma. Rise and fall times of 50 n sec are typical. This would allow modulating frequencies up to 10 MHz.

Design of the external modulation circuit will proceed during the next report period.

g. Power leveling.

Techniques for maintaining a constant field intensity were considered during this report period. Figure 1 shows the leveling subsystem. The leveling circuitry consist of a 0 to 70 db programable attenuator, field probe, crystal detector, and amplifier/filter/programmer. The leveling loop operation is as follows. Assume that zero attenuation is programmed into the attenuator. The R.F. signal passes throughout the modulator, power amplifier and tracking filter, to the antenna. The antenna field is sensed by the field probe and detected by the crystal detector. The crystal detector output is a video signal which is proportional to the RF field intensity. The video signal is filtered and amplified by the filter/amplifier. The output of the filter amplifier is a DC voltage proportional to the peak value of the RF signal. This DC voltage is applied to the external leveling input of the sweep oscillator. If the RF signal level changes, the DC voltage change will cause the signal generator power output to change in the opposite direction. Thus, leveling is achieved.

When a different field strength is required, the programmable altenuator is programmed to produce the desired field intensity at the antenna. Intentionally changing the RF Field requires that the leveling loop be compensated so that it does not respond to the change. This is accomplished by programming the offset of the filter/amplifier coincident with the programmable attenuator.

3. SYSTEM CABLING CONSIDERATIONS

Cabling and waveguide has been selected to provide low loss and flexibility. The power levels at the antenna feed which will provide the 200 v/m fields strength are as follows:

For the re-focused parabola:

Frequency F (GHz)	Power W (Watts)
2 GHz	135
4 GHz	29.5
12.4 GHz	3.3
18 GHz	1.6

For the stripline

30 to 60 MHz	40
1 to 2 GHz	40

To achieve these levels, efficiently, very low loss cable or wave guide is required between the power amplifier and the antenna feed. In addition, the cabling should be flexible to permit movement of the antenna while the system is operating and to allow for interchanging system components.

Interconnecting cable selection is:

Frequency	Cable/Wave Guide
30 - 60 MHz	1/2" Heliax Foam
1 - 2 GHz	1/2" Heliax Foam
2 - 4 GHz	1/2" Heliax Foam
12.4 - 18 GHz	WR-62 Twist Flex Waveguide.

A sample calculation of cable loss for the 2 to 4 GHz and between the power amplifier output to the antenna feed follows: (Refer to figure 3).

CABLE	TOTAL LOSS
Section B - 1/2" Heliax, 2 ft. length @ 0.05 db/ft	0.1 db
Section C - 1/2" Heliax, 2 ft. length @ 0.05 db/ft	0.1 db
Section D - 1/2" Superflexible Heliax, 5 ft. length @ 0.08 db/ft	0.4 db
Cable Loss Total	0.6 db

Adding the tracking filter loss of .5 db to the cable loss gives a total loss between the amplifer and the antenna feed of 1.1 db. With an amplifier power output of 200 watts, the power delivered to the antenna is

$$P_L = P_A \quad 10^{\frac{\alpha T}{10}} = 155.2 \text{ watts}$$

where P_L = power delivered to antenna feed

P_A = power available at Amplifier A output

αT = Total db loss

This is sufficient power to meet EMRS requirements. Similiar calculations in the remaining frequency bands yield the following results.

Band	Power Required	Power Avail
30 to 60 MHz	40 Watts	66.5 Watts
1 to 2 GHz	40 Watts	60 Watts
2 to 4 GHz	135 Watts	155 Watts
12.4 to 18 GHz	1.6 Watts	4.2 Watts

4. Test Instruments

Test instruments required for, but not part of, the demonstration EMRS would include the following:

High Impedance digital volt meter.

Frequency counter.

Modulation Signal Source.

Power Meter with probe and directional coupler.

Spectrum Analyzer.

For computer controls of EMRS functions using the IEEE-488 Interface Bus, a programmable calculator like the HP 9830A is required. In addition, if a hard copy of the program controlling the EMRS is required, a printer such as the HP 9866A would be necessary.

III. FUTURE PLANS.

During the next report period, the following progress is expected.

1. Selection and purchase of sweep oscillator.

2. Purchase of Power Amplifier.

3. Specification procurement of tracking filters.

4. Design of leveling loop and modulation circuits.

5. Further progress in fabrication and testing of antenna subsystem.

IV

ILLUSTRATIONS

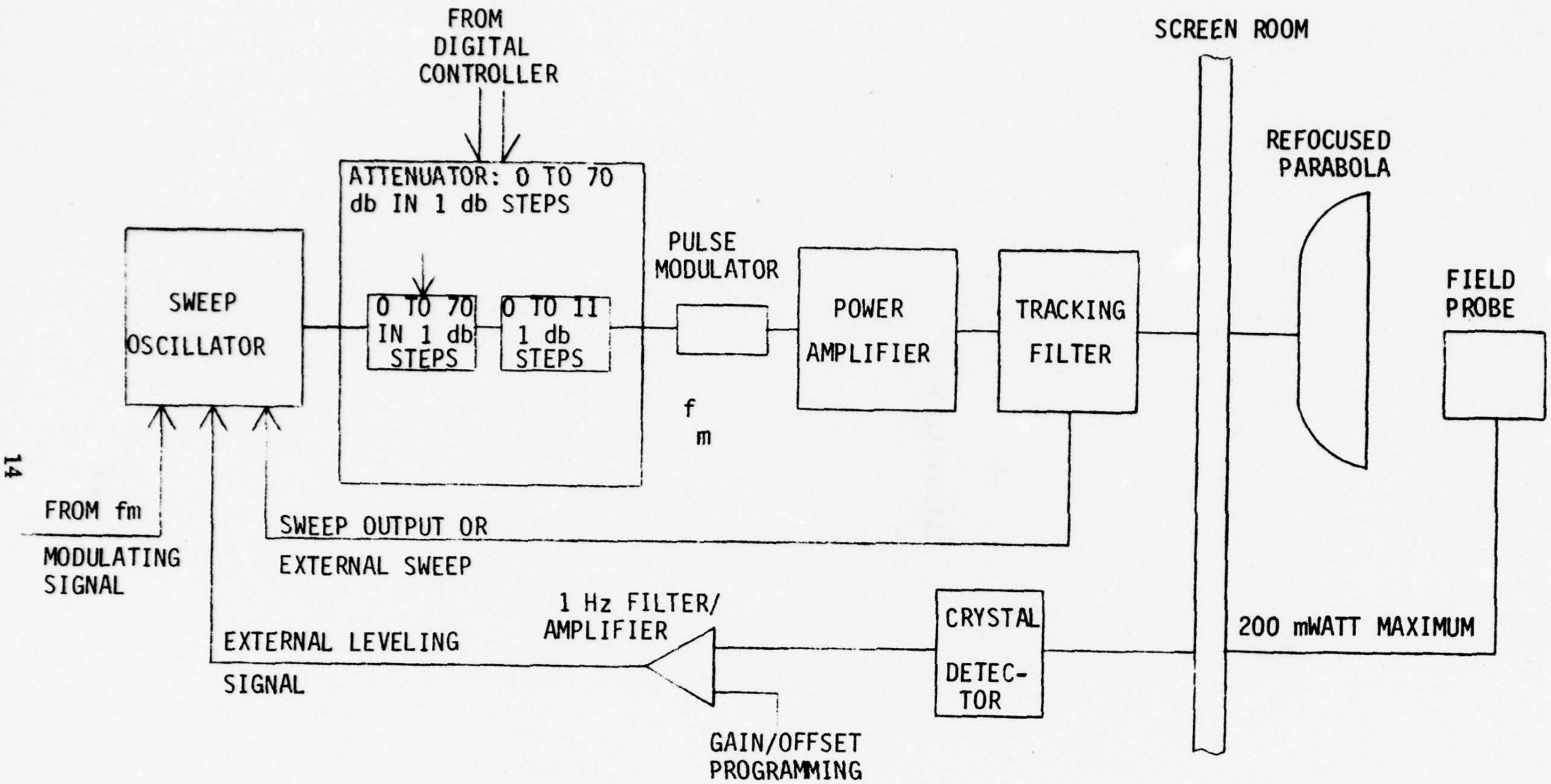

Figure 1.a. Demonstration EMRS with refocused parabola.

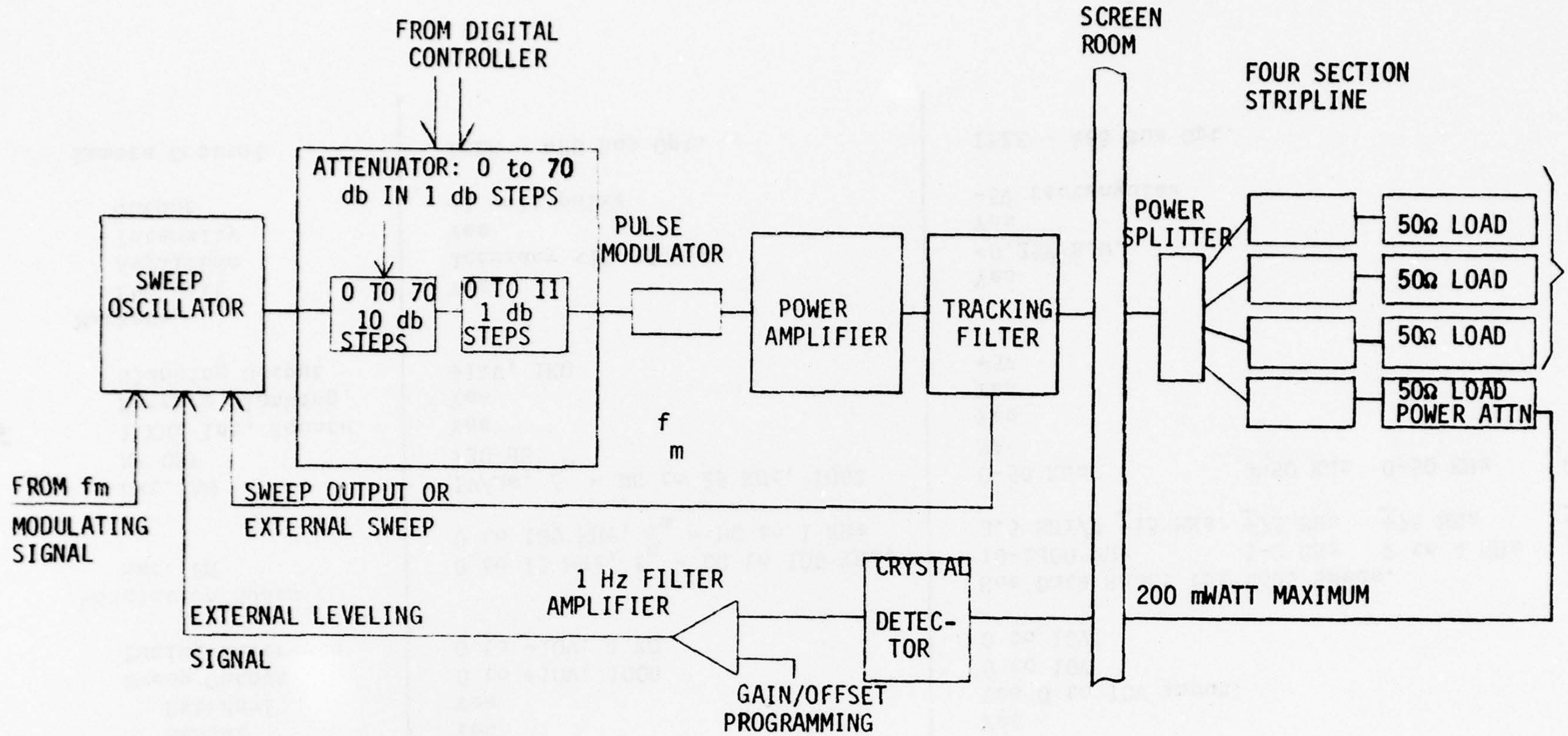

Figure 1.b. Demonstration EMRS with stripline.

PARAMETER	SYSTRON DONNER 50525-1	HP 8620C
Sweep Functions		
Full	Yes	Yes
ΔF	Yes	Yes
Marker	Yes	Yes
CW - Full Band	Yes	Yes
Trigger/Sweep Modes		
Int. Auto	Yes	Yes
Line	Yes	Yes
Manual	Yes	Yes
External	Yes	Yes 0 to 10V input.
Sweep Output	0 to +10V, 100Ω	0 to 10V
Tuning Reference	0 to -10V, 1 KΩ	0 to 10V
Modulation Modes		See Data Sheet for Mod. Specs.
Ext. FM	0 to 15 MHz, f_m = DC to 100 KHz; 0 to 100 MHz, f_m = DC to 1 KHz	10-1300 MHz: 3.5 MHz/V $\pm$15 MHz; 1-2 GHz: $\pm$75 MHz; 2 to 4 GHz: $\pm$75 MHz; 12.3-18: $\pm$75 MHz
Ext. AM	1V/mw, f_m = DC to 25 KHz, 100%	0-50 KHz; 0-50 KHz; 0-50 KHz; 0-50 KHz
RF OFF	>30 db	NA
1 KHz Int. Square	Yes	Yes
Retrace Blanking	Yes	Yes
Blanking Output	+14V, 1KΩ	+5V
Markers		
Pen Lift	Yes	Yes
Amplitude	Accuracy <1% of B.W.	<0.25% B.W.
Intensity	Yes	Yes
Output	-1 volt pulse	-5V rectangular
Remote Control	IEEE - 488 Bus Opt.	IEEE - 488 Bus Opt.

Figure 2. Sweep Oscillator Comparison (sheet 1 of 2)

PARAMETER	SYSTRON DONNER 50525-1			
RF Characters	8-112 MHz	1-2 GHz	2-4 GHz	12.4 - 18 GHz
Freq. Accuracy	± 1 MHz ± 3% of 30 MHz	±10 MHz ±1% of 1 GHz	±20 MHz ±1% of 2 GHz	±56 MHz 0.45%
Freq. Linearity	± 1%	± .5%	± .5%	± .3%
Power Output				
Leveled (Int)	≥10 dbm	10 dbm	10 dbm	10 dbm
External Leveled	14.7 dbm	13.0 dbm	10.4 dbm	10 dbm
Power Variation	±0.5 db	=	=	=
Freq. Stability vs. Temperature	±75 KHz/°C	±500 KHz	± 1 MHz/°C	±3.75 MHz/°C

	HEWLETT-PACKARD 8620C			
RF Characters	10-1300 MHz	1-2 GHz	2-4 GHz	12.4 - 18 GHz
Freq. Accuracy	± 10 MHz 30% of 30 MHz	±15 MHz 1.5%	±15 MHz 0.75%	± 70 MHz 0.6%
Freq. Linearity	1%	1%	1%	1%
Power Output				
Leveled (Int)	10 dbm	13 dbm	13 dbm	10 dbm
External Leveled	10 dbm	13 dbm	13 dbm	10 dbm
Power Variation	Not. spec.	± 0.1 db	=	=
Freq. Stability vs. Temperature	±600 KHz/°C	±500 KHz/°C	±500 KHz/°C	± 5.4 MHz/°C

Figure 2. Sweep Oscillator Comparison (sheet 2 of 2).

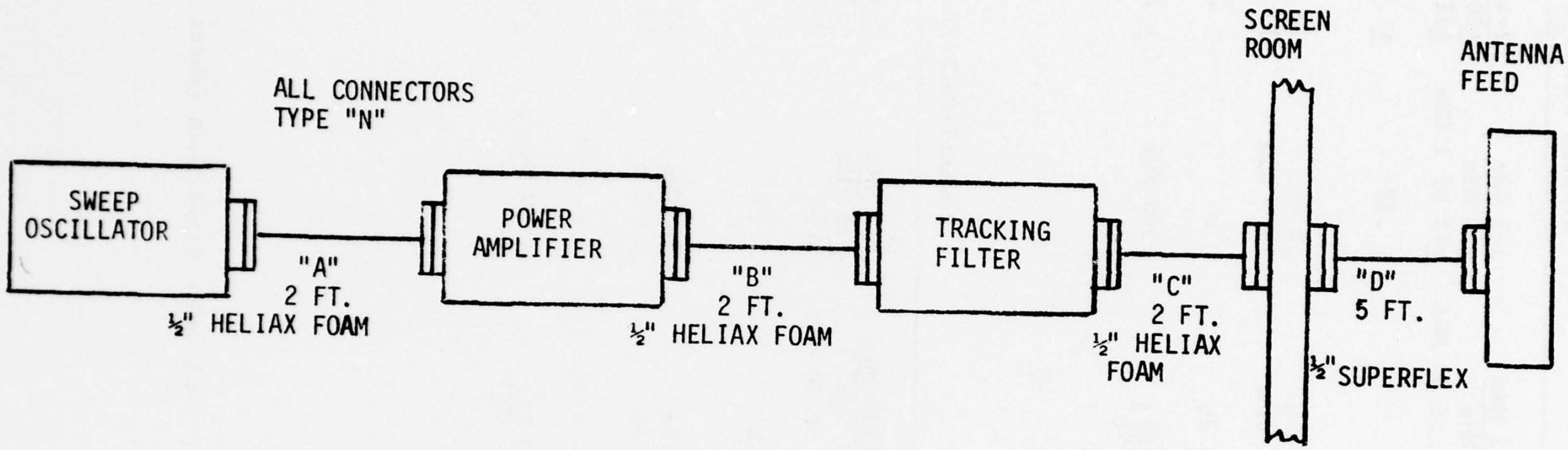

Figure 3. Block diagram showing interconnecting cables.

V. APPENDIX.

1.0 TUNABLE BANDPASS FILTERS

1.1 PURPOSE

Some RF power sources, such as helix TWT's, have severe spurious output signals. These spurious signals are of major concern because of their relatively close proximity to the desired output signal. Spurious signal suppression switching through a series of bandpass filters would require a very large quantity of filters and a complex switching network. The large quantity of filters would be required because each filter would have to have a passband narrow enough to provide the required spurious signal rejection.

A more cost effective method of obtaining the required spurious rejection would be to employ tunable bandpass filters. Tunable filters would be made to track the frequency of the signal source. These bandpass filters could be made with a passband just large enough to pass the desired signal modulation badwidth plus enough excess to tolerate nominal tracking error. This passband would be considerably narrower than that provided by switched bandpass filters. This narrow passband would allow the spurious rejection requirement to be met with fewer filter sections.

1.2 TUNING METHOD

The tunable bandpass filters would have to be mechanically tuned. Electronically tuned filters (varactor diode or ferrite tuned) at the power levels required for the EMRS, would generate spurious and harmonic signals of their own. Mechanically tuned filters have a relatively slow tuning rate but they can provide much higher Q factors than electronically tuned filters. The higher Q is desirable to minimize power loss.

1.3 ELECTRICAL DESIGN

Specific filters for each frequency band will be designed after a careful analysis is performed on each signal source to determine specific rejection requirements. The following example is presented to show typical filter parameter capabilities.

Suppose a 2-4 GHz signal source, having a $\pm$ 25 MHz FM deviation, has -20 dBc harmonics and -60 dBc spurious signals. Then the output filter must provide 80 dB harmonic rejection and 40 dB spurious rejection. The filter passband must not be less than 50 MHz (assuming the modulating frequency is low enough to be neglected).

First the number of filter sections will be determined. A one section filter would be mechanically ideal. However, the 40 dB/3 dB selectivity ratio for one section is only 100, i.e., the 40 dB rejection bandwidth is 5 GHz for a 50 MHz passband. This, of course, is totally unusable. Table I shows the change in selectivity ratio as the number of filter sections is varied from 1 to 4 and the rejection bandwidth is held constant at 50 MHz. A two section filter is still not practical for some signal sources. The mechanical degree of difficulty is about the same for a three or four section filter since the tuning

TABLE 1

SELECTIVITY RATIOS FOR BANDPASS FILTERS

No. Sections	1	2	3	4
40dB/3dB Ratio	100	10	4.7	3.2
40dB Bandwidth, MHz for 50 MHz Passband	5000	500	235	160
80dB/3dB Ratio	10,000	100	21.6	10
80dB Bandwidth, MHz for 50 MHz Passband	500,000	5000	1080	500

rate for the center section of a three section filter is similar to the tuning rate of the middle two sections of a four section filter, and in both cases, different than the tuning rate of the end sections. Therefore, a four section filter will be selected for its greater selectivity.

The filter 3 dB bandwidth is selected to be 3%. This will provide approximately a 1% tracking tolerance in addition to the modulation bandwidth. Table 2 shows the parameters for a 3% bandpass with four sections and an unloaded Q of 2000. This Q value is based on a one inch diameter cavity fabricated with standard manufacturing practices. Larger cavity sizes would reduce the frequency at which spurious passband responses could occur. An auxiliary lowpass filter will be required to provide rejection at the normal stopband re-entrance that occurs at approximately 3 times the center frequency. The capacitive loading that tunes the filter will raise the frequency of this re-entrance somewhat, however, a low pass will still be required.

The bandpass filter design for specific frequency bands or signal sources will be similar to the above with possible variations to optimize rejection bandwidth (stopband levels) or insertion loss.

1.4 MECHANICAL DESIGN

The filter will utilize a solid state servo positioning unit to tune the desired frequency.

TABLE 2

FILTER BANDWIDTH AND INSERTION LOSS

Center Frequency, GHz	2	3	4
3dB Bandwidth, MHz	60	90	120
40dB Bandwidth, MHz	192	288	384
80dB Bandwidth, MHz	600	900	1200
Insertion Loss, dB	.75	.65	.60

The positioning unit will be geared to the tuning mechanism of each filter using an anti-backlash gearing system to minimize mechanical hysterisis and the possibility of frequency drift. Operating torque estiments of 100 oz-inches, delivered at the output shaft, will be required. Rotational speeds consistent with this torque will provide a sweep rate of approximately 35 seconds to cover the filters' frequency range.

It would be desirable to operate the filter with a triangular waveform rather than a sawtooth which is typically used in sweep generators. A triangular waveform could be obtained from a separate waveform generator, which then could be used to control both the sweep generator and the tunable filter.

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